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AN EXPERIMENTAL STUDY OF DRILLING OF HARD-TO-CUT GRADE 5 TITANIUM ALLOY USING COBALT DRILL BITS

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ABSTRACT

Titanium is found to be one of the hardest elements and hence machining of Titanium has always been considered as a challenge in the manufacturing field. Out of all machining process, drilling is considered to be difficult and has to be done with much care and perfection because undercut or overcut holes may result in the failure of the particular part or assembly. Hence, it is very important to study more about drilling parameters on hardest metal like Titanium as the drilling of titanium is a tedious task than other machining operations. In this present work, drilling was done on a Ti-6Al-4V plate with cobalt drills of different diameters of 6 mm, 8 mm and 10 mm. A study is done on the Force (F_t), Torque (M_t) and Temperature (T) is carried out. The drill bits are analyzed before and after drilling using Scanning Electron Microscope to compare the wear pattern of the drill bits.

KEYWORDS: Titanium, Drilling, Ti-6Al-4V, Cobalt, Temperature, Force, Torque & SEM

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Original Article

1. INTRODUCTION

Machining is a procedure of eliminating undesirable material by the productive utilization of cutting tool. From the time machining was introduced, machining of metals was treated as a tough job, as selection of wrong parameters will affect the cutting tool and the entire process, resulting in wastage of time and material cost. Out of many machining operations, drilling of metals has been considered to be tough, as it involves deep material removal. During this type of material removal, there will be development of high temperature, which will restrain the progression of drilling by causing wear to the drilling tool and eventually result in the failure of the tool. Also, in case of hard to cut metals, drilling operation on such hard to cut metals are always considered a difficult task, as the probability of cutting tool getting damaged due to high temperature and wear is more compared to other machining operations. Also, while drilling, if the drill tool is not able to overcome the properties of material being drilled, then it will result in a catastrophic failure of drill tool.

Titanium and other hard–to-cut metals have posed a challenge to the machining engineers [1,2] by causing failure of cutting tools due to the high temperature that is generated at the tool-workpiece interface [3]. In the case of drilling, if the drill tool is not selected appropriately in many cases, it is found that as soon as the drill bit touches the workpiece, it is subjected to heavy amount of wear due to the high amount of friction, and in some cases, the drill bits melted off due to the very high temperature produced, as the result of friction at the interface point. Hence, in case of hard–to-cut metals like Titanium, drilling operation must be performed very carefully by selecting proper drill tool, right amount of speed and feed rate.

Titanium and its alloys are used widely in aerospace [4], automotive [5], marine field due to their excellent material properties. They are also widely used in medical [6] and food processing industry due to their

biocompatible features. In the case of Grade 5 Ti-6Al-4V alloy, it is widely used in aerospace field due to the excellent material and corrosion-resistant properties of the particular grade. Considering the number of fittings and fixtures required in aerospace field, drilling process has a major part out of all machining operations. Hence, a detailed study about the drilling of Titanium and its alloys is a never-ending topic among researchers [7]. Though there have been several studies pertaining to turning and other machining operations on Titanium, there have been very less studies done on the drilling of Titanium. This may be due to the fact that drilling of Titanium causes severe tool failure through tool wear and heavy temperature.

Some of the researchers have pointed out that even though Titanium is rich in material properties and is an excellent metal to use in different critical conditions, the poor machinability of this metal is a major drawback. There are many factors contributing to the poor machinability of Titanium and its alloys apart from being a hard element. Normally, during machining, when a tool intends to cut the parent material, it comes out as chips. In the case of Titanium, it is found that very high temperature produced at the tool workpiece interface hinders this plastic deformation that is required to form chips. While drilling due to the material hardness, it implies high stress on to the tool, which results in the failure of the tool. Titanium has a high coefficient of friction between the tool and the workpiece [8], which results in catastrophic failure of the tool. There were also instances of titanium’s tendency to ignite as a result of high temperature produced during drilling. All these factors alone or together cause rapid wear of the tool and results in a failure of tool, which in turn causes wastage of time and material costs.

2. MATERIALS

2.1. Workpiece

The parent material selected in the present work is Titanium alloy named Ti6Al4V, Ti-6Al-4V, or Ti 6–4 is also known as Grade 5. It has a chemical composition of 90% Titanium, 6% Aluminium and 4% Vanadium. On comparing this grade, it is found to be stronger than CP Titanium but has good thermal and stiffness properties. Another highlight of this particular grade is that it is heat treatable. This grade is famous for its excellent combination of strength, corrosion resistivity, weldability and fabricability. Ti-6Al64V can be used in critical applications as well as in applications, which may range up to 400^{o}C.

The physical and mechanical properties of Ti-6Al-4V can be found in Table 1. The plate used for experiment is displayed in Figure 1.

Ti-6Al-4V standard specifications include:

- UNS: R56400,
- AMS: 4911, 4920, 4928, 4934–4935, 4965, 4967, 6930–6931, T9046
- ASTM: B265, B348, B381 F136
- MIL: T9046–T9047
- MMS: 1217, 1233
- DMS: 1570, 1583, 1592, 2285, 2442 R-1
- BMS: 7-348

Table 1: Physical and Mechanical Properties of Ti-6Al-4V

Property	Young's Modulus (Gpa)	Shear Modulus (Gpa)	Bulk Modulus (Gpa)	Poisson's Ratio	Yield Strength (Mpa)	Ultimate Strength (Mpa)	Hardness Rockwell C
Min	110	40	96.8	0.31	880	900	36
Max	119	45	153	0.37	920	950	36

Figure 1: Ti-6Al-4V Plate (100 x 60 x 5 mm).

2.2. Drill Bits

In the present work, Cobalt drill bits were used to perform drilling operation on the proposed Titanium plate. Cobalt drill bits are made from Cobalt steel with a large percentage of Cobalt. This makes the drill bit remarkably hard. These drill bits are considered to possess good resistance to temperature. Cobalt drill bits are a preferred choice in production drilling, which involves continuous work. Cobalt drill bits of 6 mm, 8 mm and 10 mm diameters are selected for the present work. The drill bits used for the experiment is displayed in Figure 2.

Figure 2: Cobalt Drill Bits (Dia: 6 mm, 8 mm, 10 mm).

3. EXPERIMENTAL WORK

3.1. Energy Dispersive X-ray Analysis

For the elemental analysis of the procured Titanium workpiece, Energy Dispersive X-Ray Analysis (EDXA) was carried out on the Ti-6Al-4Vplate, which was used for the experiment. The spectrum obtained in EDXA clearly displayed 90%

Titanium, 6% Aluminium and 4% Vanadium as seen in Figure 3.

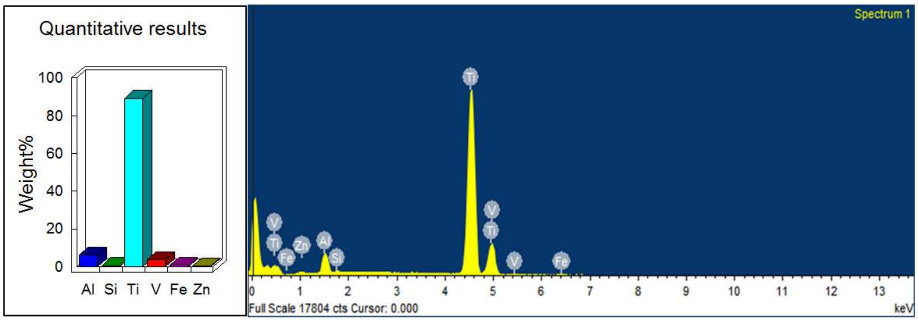

Figure 3: EDXA Spectrum of Ti-6Al-4V Plate.

3.2. Drilling Parameters and Machine Setup

The input parameters were Speed, Feed rate and Drill diameter and output responses of Force, Torque and Temperature were recorded. The input parameters used for the experiment are listed in Table 2.

Table 2: Drilling Parameters

Drilling Parameters	Level 1	Level 2	Level 3
Spindle speed (RPM)	500	750	1000
Feed rate (mm/min)	20	40	60
Drill diameter (mm)	6	8	10

The drilling experiment is performed on a conventional Vertical Machining Center (VMC) available at Karunya University, Coimbatore. The Force and Torque is measured using a three-component Kistler dynamometer coupled with the VMC. The Kistler charge amplifier interface receives the data signals and stores it in the computer. Titanium plate mounted on the Kistler dynamometer is displayed in Figure 4. The specifications of the dynamometer used for this experiment is displayed in Table 3.

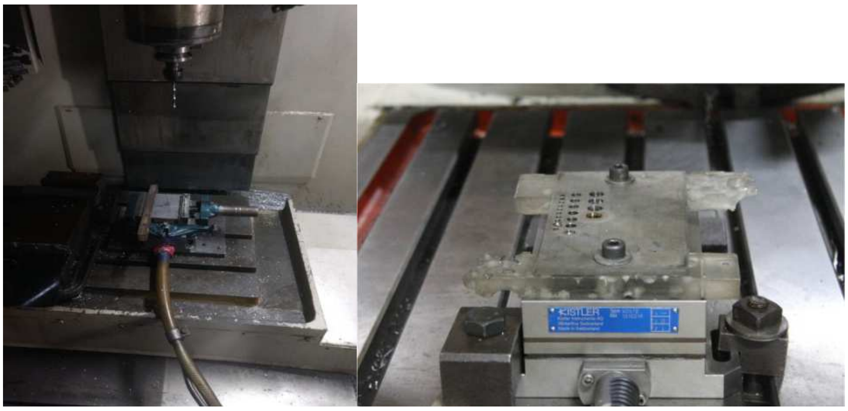

Figure 4: Ti-6Al-4V Plate Mounted on the Kistler Dynamometer.

Table 3: Dynamometer Specifications

Parameter	Specification
Type	Calibrated 9272
Weight	4.2 kg
Accessories: Connecting cable type	1677A5/1679A5
Type of Sensor	Torque sensor
Number of Channels	3 charge amplifier channels

Transducer Sensitivity	Fx = –7.8PcN^{-1} Fy = –3.5PcN^{-1}
Natural Frequency	fn[x], fn[y] = 3.1 KHz fn[z] – 6.3KHz
Protection Class	IP67
Operating Temperature	0–70°C

4. RESULTS AND DISCUSSIONS

4.1. Force, Torque and Temperature Measurements

ATi-6Al-4V plate of 100 x 60 x 5 mm dimensions were drilled using 6-mm, 8-mm and 10-mm-Cobalt drill bits using a L9 orthogonal array principle to study about the development of Force (F_t), Torque (M_t) and Temperature (T) produced during drilling. Graphs for Force and Torque were obtained from the computer system coupled with Kistler dynamometer on which the Titanium plate was mounted. Temperature was measured using a Infrared thermometer.

The Force (F_t), Torque (M_t) and Temperature (T) readings recorded during the drilling experiment is displayed in Table 4.

Table 4: Input and Output Parameters in Taguchi L9 Orthogonal Array

Sl. No.	Input Parameters			Output Parameters		
	Speed (RPM)	Feed (mm/min)	Drill DIA. (mm)	Thrust Force (N)	Torque (Nm)	Temp (°C)
1	500	20	6	549.6	50.74	44
2	750	60	6	924.2	64.01	50
3	1000	40	6	1400	86.36	74
4	500	40	8	639.0	69.05	62
5	750	20	8	1240	74.92	85
6	1000	60	8	696.0	29.75	46
7	500	60	10	2139	480.7	106
8	750	40	10	508.3	36.77	60
9	1000	20	10	813.0	163.7	75

A set of Force and Torque graphs obtained during the experiment is displayed in Figure 5.

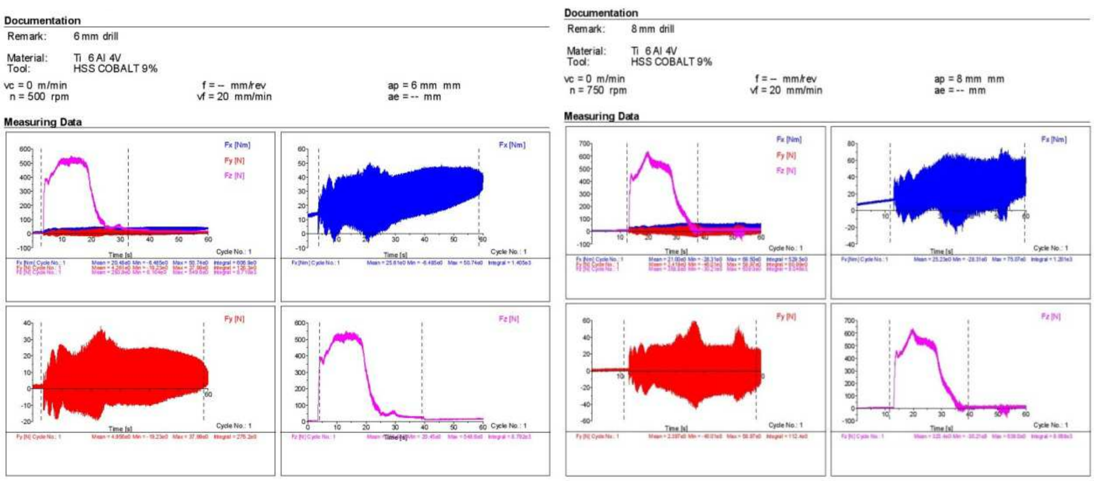

Figure 5: Sample Force and Torque Graphs Obtained During Drilling Experiment.

4.2. Material Removal Rate (MRR) Calculation

Material Removal Rate (MRR) is the amount of material removed during the drilling with respect to drilling time. It may be defined as the volume of material removed by the drill per unit time.

After the drilling experiment, the Material Removal Rate during the drilling experiment was calculated. The readings are displayed in Table 5.

Table 5: Material Removal Rate Readings

Sl. No.	Speed (RPM)	Feed (mm/min)	Drill Dia. (mm)	MRR
1	500	20	6	0.188
2	750	60	6	0.847
3	1,000	40	6	0.753
4	500	40	8	0.502
5	750	20	8	0.376
6	1,000	60	8	1.507
7	500	60	10	0.942
8	750	40	10	0.942
9	1,000	20	10	0.628

4.3. Burr Height Measurement

Burrs are unwanted projections in the metal after the machining operation. Burr is formed as a result of deformation of metal during the drilling operation. If there is more burr during machining operation, then more time and money has to be spent for deburring the metal surface for obtaining a smooth surface. Hence, it is important to obtain non-burred surface. Burr formation as a result of drilling experiment on Ti-6Al-4V is displayed in Figure 6. Burr height measured readings are displayed in Table 6. From the results, it is seen that the 9th hole has very high burr formation.

Table 6: Burr Height Readings of Each Holes

Sl. No.	Diameter of Holes (mm)	Mean Measured Value (mm)
1	6	0.467
2	6	0.215
3	6	0.649
4	8	0.353
5	8	0.297
6	8	1.280
7	10	1.163
8	10	0.198
9	10	2.714

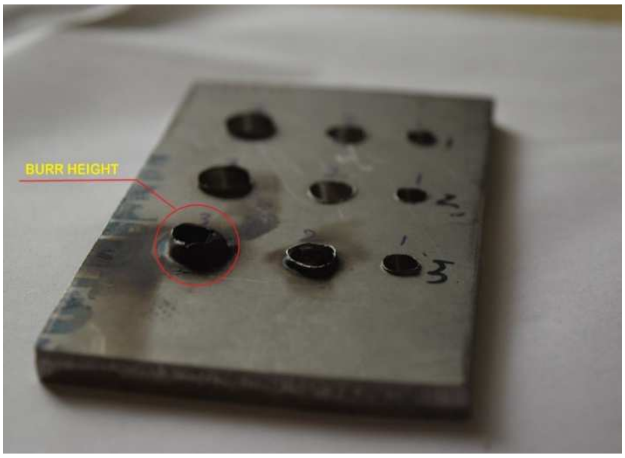

Figure 6: Burr Height.

4.4. SEM Analysis

Cobalt drill bits used in the experiment were subjected to Scanning Electron Microscopy (SEM) before and after drilling process to analyze the wear occurred on the drill bits as a result of drilling experiment and is displayed in Figures 7–12.

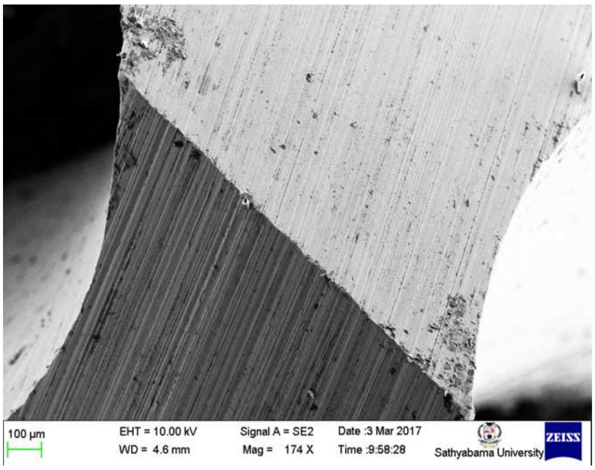

Figure 7: 6-mm Cobalt Drill Bit before Drilling.

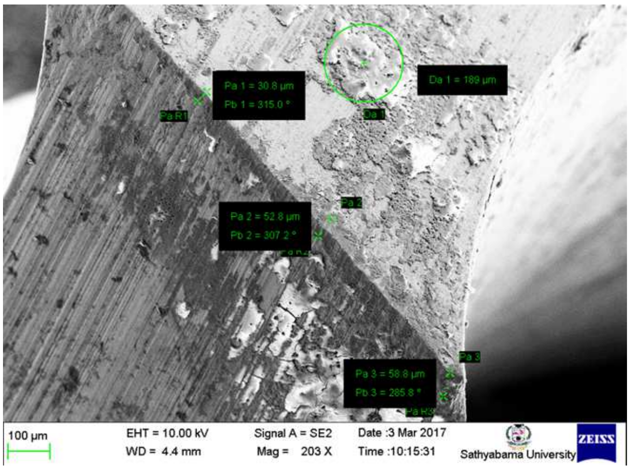

Figure 8: 6-mm Cobalt Drill Bit after Drilling.

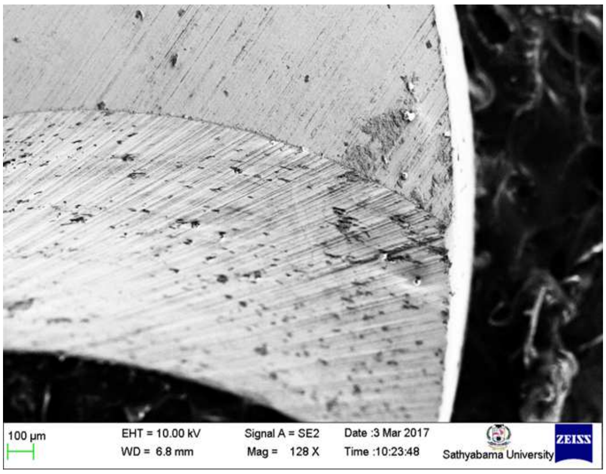

Figure 9: 8-mm Cobalt Drill Bit before Drilling..

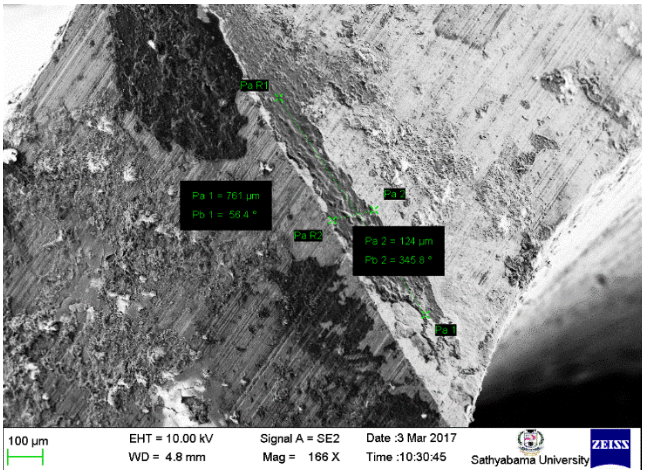

Figure 10: 8-mm Cobalt Drill Bit after Drilling

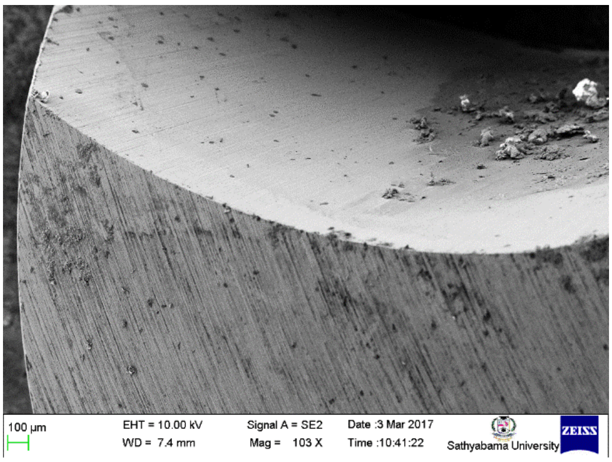

Figure 11: 10-mm Cobalt Drill Bit before Drilling.

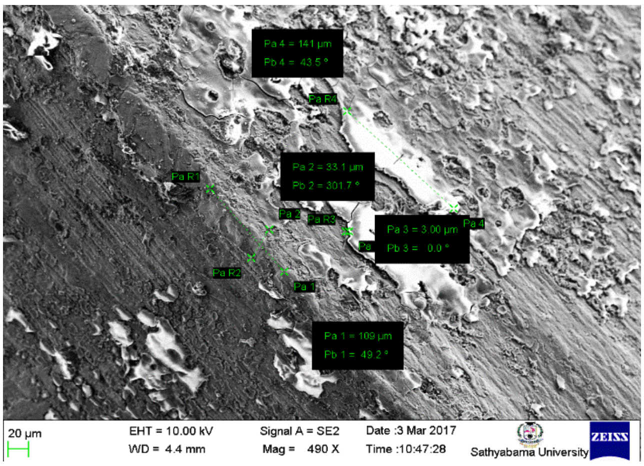

Figure 12: 10-mm Cobalt Drill Bit after Drilling.

SEM analysis of drill bits after drilling as displayed in figures 8, 10 and 12 reveals significant wear and indicates the deposition of parent material on the tool.

5. CONCLUSIONS

In this paper, authors have made an attempt to experimentally study the drilling parameters and their effects on drilling of Ti-6Al-4V using Cobalt drill bits. Material removal rate and burr formation during drilling of a hard-to-cut metal like Titanium was studied. Also, focus was shed on the tool wear pattern formed on the drill bits as a result of drilling using SEM analysis. The following conclusion may be drawn from the experiment:

- At higher speed and feed rates, there was rapid increase of drilling temperature.
- Mechanisms of tool wear was observed when there was increase in the temperature during drilling.
- The 10-mm drill bit was the most affected by wear.
- Also, it was observed that when the speed is high, there was significantly high burr formation.
- SEM analysis clearly pictured the wear pattern on the drill bits after drilling.

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Mr. Nivin Joy, currently working as an Assistant Professor in the School of Mechanical Engineering at Sathyabama Institute of Science and Technology, Chennai, completed his Post Graduation in Computer Aided Design and is pursuing Doctorate in the field of drilling of Titanium alloys. He has published a good amount of Web of Science and Scopus publications. He is also interested in the field of Energy, Biodiesel and New Materials. He is currently concentrating in modeling and optimization of different case studies using software package like Minitab.

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